

To Appear in: The Human Mission to Mars: Colonizing the Red Planet,
Joel S. Levine and Rudy Schild, Editors, Cosmology Science Publishers, 2010

Humans to Mars: The Greatest Adventure in Human History

Joel S. Levine¹ and Rudy Schild²

¹Science Directorate, NASA Langley Research Center, Hampton, VA 23681-2100,
joel.s.levine@nasa.gov

²Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138,
rschild@cfa.harvard.edu

The human species is on the verge of achieving an historic accomplishment. Plans are being developed for a human mission to Mars, which will make the human species the first two-planet species. The last and present Presidents have proposed a human mission to Mars as a national goal of the United States.

The reasons for a human mission to Mars are many and include (1) World technological leadership, (2) Enhanced national security, (3) Enhanced economic vitality, (4) The human urge to explore new and distant frontiers, (5) Scientific discovery (how did Mars evolve from an early Earth-like, hospitable planet to its present inhospitable state? Is there life on Mars?) (6) Inspiring the American public and the next generation of scientists and engineers (following the launch of Sputnik I by the USSR on October 4, 1957, the U. S. and the rest of the world witnessed a significant increase in the number of students going into science and engineering), (7) Develop new technologies for potential non-space spin-off applications, and, (8) Enhanced national prestige, etc. Other reasons for colonizing the Red Planet are more catastrophic in nature, including Mars as a safe haven for the survival of the human species in the event of an impact with a large asteroid (remember the demise of the dinosaurs 65-million years as a result of an asteroid impact!). Some have also suggested that the colonization of Mars may be a solution to the global exponential population explosion on our planet!

A human mission to and the colonization of the Red Planet requires multi-disciplined expertise in many areas including engineering, technology, science, human health and medicine and the human psychological and behavior. To capture the relevant areas of needed expertise, we have invited a group of more than 70 U. S. and foreign experts in these areas, including astronauts, scientists, engineers, technologists, medical doctors, psychologists and economists to share their views and thoughts on a human mission to Mars. All submitted papers were peer-reviewed by at least 3 reviewers.

Why humans? Humans are unique scientific explorers and observers. Humans have unique capabilities for performing scientific measurements, observations and sample collecting. Human attributes to exploration include: intelligence, adaptability, agility, dexterity, cognition, patience, problem solving in real-time, in situ analyses - more

science in less time! Humans could obtain previously unobtainable scientific measurements on the surface of Mars. Humans possess the abilities to adapt to new and unexpected situations in new and strange environments, they can make real-time decisions, have strong recognition abilities and are intelligent. Humans can perform detailed and precise measurements of the surface, subsurface and atmosphere while on the surface of Mars with state-of-the-art scientific equipment and instrumentation brought from Earth. The increased laboratory ability on Mars that humans offer, would allow for dramatically more scientific return within the established sample return limits. The scientific exploration of Mars by humans would be performed as a synergistic partnership between humans and robotic probes, controlled by the human explorers on the surface of Mars. Robotic probes could explore terrains and features not suitable or too risky for human exploration. Under human control, robotic probes could traverse great distances from the human habitat covering distances/terrain too risky for human exploration and return rock and dust samples to the habitat from great distances.

Section I. Astronauts on Mars includes 5 articles by NASA Astronauts, including Apollo lunar astronauts, Edgar Mitchell (Apollo 14 Lunar Module Pilot, the sixth person to walk on the Moon) and Harrison Schmitt (Former U. S. Senator and Apollo 17 Astronaut and the 12th and last person to set foot on the Moon), Space Shuttle Astronaut Steven A. Hawley (a veteran of 5 Space Shuttle flights from 1984-1999) and Don Pettit (a veteran of 2 Space Shuttle flights, lived aboard the International Space Station for 5-1/2 months and returned to Earth on Russian Soyuz spacecraft).

As a species we have always had an incredible curiosity and because of it the thought of exploration and exploitation of new frontiers has always excited our imagination and motivated our efforts. We now stand on the threshold of becoming a space faring civilization. Our very survival certainly for the long term depends upon it and probably for the near term as well. Throughout our history, we have never been able to predict the perils nor the benefits of exploration but in every case humanity has always prevailed over all obstacles and the rewards it has reaped have always far exceeded our expectations. This certainly will be the case with the exploration of Mars and the other planets and the moons of our solar system. Initially these will be purely exploratory missions but eventually exploration will turn to colonization. Ultimately as we continue to develop and our technological capabilities even the stars will be open to our explorations. Will humanity be prepared for the greatest discoveries of the history of our civilization? Will we find other intelligent civilizations far older and incredibly superior than our technological capabilities and collective wisdom? We end with speculation on the values, ethics and consciousness of these civilizations and lessons they may hold for the future of humanity.

Section II. The Future is Mars... 3 articles discuss why explore Mars with humans and the plan and risks associated with the human exploration of Mars. An historian asks: Why should humans explore Mars? In debating an answer to this question, the space community has revealed a deep divide: one that extends beyond policy to touch at the basic meaning of exploration. While a scientific vision of Mars, with a focus on

telerobotic exploration, may not excite the public to the same extent as human missions, it is achievable within the current fiscal climate.

Section III, To Boldly Go: Getting to Mars and Design Reference Architecture: 4 papers cover the new U. S. Mars Design Reference Architecture 5.0 (Mars DRA 5.0), Earth to Mars planetary trajectories, the technological challenges of Mars entry, descent and landing (EDL) and the advantages and cost-savings of a one-way mission to Mars. During the past several years, NASA has either conducted or sponsored numerous studies of human exploration beyond low-Earth orbit. These studies have been used to understand requirements for human exploration of the Moon and Mars in the context of other space missions and research and development programs. Each of these exploration architectures provides an end-to-end reference against which other mission and technology concepts can be compared. The 2007 Mars Design Reference Architecture 5.0 (Mars DRA 5.0) is the latest in a series of NASA Mars reference missions. It provides a vision of one potential approach to human Mars exploration. The strategy and example implementation concepts that are described here should not be viewed as constituting a formal plan for the human exploration of Mars, but rather provide a common framework for future planning of systems concepts, technology development, and operational testing as well as potential Mars robotic missions, research that is conducted on the International Space Station, and future exploration mission to the Moon or near-Earth objects. The Mars DRA 5.0 provides an overview of the overall mission approach, surface strategy and exploration goals, as well as the key systems and challenges for the first human missions to Mars.

Section IV. The Scientific Investigation of Mars: Humans, Geology, Geophysics, Atmosphere, Climate and Biology: As already noted, scientific discovery is a driver for a human exploration of Mars. Some of the key scientific questions for human exploration in geology, geophysics, atmosphere, climate, biology and the search for life is outlined and discussed in 5 papers in this section. Mars is both a unique and complex world. Many of the same processes/mechanisms have operated/operate on both Earth and Mars. Processes/mechanisms common to both Earth and Mars include (1) an early heavy bombardment is found in the geological record of both planets, (2) impact craters are recorded on the surface of both planets, (3) planetary dipole magnetic fields existed on both planets (Mars lost its planetary dipole field in its early history), (4) evidence of widespread and extensive volcanism are found on both planets, (5) the presence of past (Mars) and present (Earth) liquid water on the surface, (6) the existence of geochemical cycles on both planets, and (7) the condensation of atmospheric gases forming polar caps (water vapor on Earth and carbon dioxide on Mars). Measurements indicate that Earth and Mars experienced very divergent paths of evolution. The geological record suggests that the atmosphere/climate of Mars changed significantly over its history. Early Mars may have possessed a much denser atmosphere, perhaps with an atmospheric pressure in excess of 1000 millibars, the surface pressure of the Earth's present-day atmosphere. A denser atmosphere on Mars would have permitted liquid water on its surface. Present-day Mars has a thin (6 millibars) cold atmosphere, devoid of any surface liquid water. Why has Mars changed so drastically over its history? How and why has the habitability of

Mars changed over its history? Is there a message in the history of Mars to better understand the future of the Earth?

Section V. Psychology, Stress, Behavioral Health of Astronauts & Crew: The human mission to Mars involves human factors, behavioral health, psychosocial adaption, stress, psychological, and psychiatric issues as outlined in the 5 papers in this section. To support living and working in space we must seek robust, reliable and user-friendly environments; synergistic life support systems that provide extra margins of safety and comfort; well designed equipment and tools; the reasoned use of artificial intelligence and robotics; and outstanding supplies. We must also seek countermeasures to the performance-threatening effects of microgravity, insufficient sleep, disruption of biological rhythms, and excessive workloads. Research in group dynamics and teamwork offers useful recommendations in such areas as leadership, communication, group decision-making, and autonomy. Behavioral health refers to an absence of neuropsychiatric dysfunction and the presence of positive interactions with the physical and interpersonal environment, and we may expect a strong positive correlation between behavioral health and performance.

Section VI. Medical Health, Physiology, Biomedical Risks of a Journey to Mars: A human mission to Mars lasting more than 6 months each way presents a series of medical challenges involving microgravity, radiation, and the space environment as discussed in 8 papers in this section. This millennium marks a new era with the 40-year anniversary of the moon landing experience and over 50 years of human space exploration. Multinational crews of the National Aeronautics and Space Administration (NASA), the Russian, Canadian, European Space Agency, and Japanese space programs have made major developments in space-related research both in low Earth orbit and onboard the International Space Station (ISS). Although the primary research and technology development for space exploration has been through the ISS, (and potentially moon exploration over the next decade), Mars represents a principal focus of space explorations. Mars is however much farther for astronauts to travel. Hence, this journey will depend on the time and place Mars is in its orbit around the sun. Mars is at its farthest from the Earth at 399 million km and closest at 56 million km, therefore a feasible launch date would be during this stage. Considering the distance involved and Mars orbit, with current propulsion systems, the time to reach Mars with an approximate 60-day surface stay will be approximately eighteen months. Landing a human crew on Mars will mark the first time in human history that we visit another planet, however the journey comes with great risks and challenges.

Section VII. Planetary Protection and Infection Risks on Mars: Planetary protection is a major problem for a human mission to Mars and involves both forward and backward protection as discussed in 3 papers in this section. If humans are going to Mars to accelerate the pace of potential scientific discovery, to learn whether or not Mars is the abode of non-terrestrial life, then a human mission is beneficial only if the human explorers will not erase or obscure the data they are traveling to Mars to discover. For example, Earth microbes will have to be kept from those places on Mars (a.k.a., "special regions") where they might grow and thrive on their own, and if Mars has its own life then human explorers should only be exposed to Martian materials under controlled

conditions that ensure their safety—and their ability to return to Earth without endangering our home planet. For any such voyage, provisions against the contamination of Mars by Earth organisms ("forward contamination") and against the contamination of Earth by possible Martian organisms ("backward," or "back contamination") are important aspects of mission success. In the event that Mars is to become a home for a future branch of humanity, then provisions for managing the potential contamination of Martian habitable zones and particularly possible Martian aquifers will be especially important.

Section VIII. The Search for Life on Mars: One of the key questions in all of science is whether life exists or existed on Mars. Over the last few years, a series of laboratory experiments and robotic missions to Mars have attempted to answer this question. The 9 papers in this section address different aspects of the search for life on Mars based on new information about the survival of microorganisms in extreme Earth and Mars-like environments and space probe measurements ranging from a re-examination of Viking Lander measurements obtained in 1976 to new measurements from the Phoenix Lander in 2008. Halophilic Archaea have adapted to a life in the extreme but could they thrive on a different planet? And even if they cannot survive there today, would those organisms leave detectable traces of their past existence for us to find? On Earth, halophilic Archaea can be found in many different environments, yet two of those environments are of particular interest in the search for extraterrestrial life: modern stromatolites and ancient halite. Stromatolites may have been around for 3.5 billion years and could have probably been the first microenvironments sheltering life. Halite has been shown to preserve living organisms for more than 400 million years. Both, stromatolites and ancient halite have been found to be habitats for one archaeal family, the family *Halobacteriaceae*. An intriguing location to search for halophiles (or their remnants) outside Earth is Mars, as it may have been a wetter and warmer place in the past and recent data suggest the presence of halite on Mars.

Section IX. Mars Base, Exploration and Colonization of the Red Planet: The Mars base and the colonization of the Red Planet are discussed in 6 papers in this section. Much effort has been spent over the past two decades on the development of plans for the human exploration of Mars, and, while the allocation of functions to specific vehicles has differed, consensus has formed around a conjunction mission (nominally 18 months on the surface) with pre-emplacement of some assets and some level of in situ resource utilization (ISRU). The exploration program as a whole is envisioned as a sequence of several independent missions, each sent to a different area of interest on Mars, analogous to the Apollo approach to lunar exploration. Creation of a quasi-permanent Mars base is envisioned as following later, at a site to be identified during the initial exploration campaign. This paper argues that a better initial human exploration campaign – i.e., one which will ultimately maximize scientific payoffs and minimize costs and risks, both to crew safety and mission success – is one in which multiple (nominally two, perhaps three) crews land at a single site and live and work in a small underground base habitat constructed in advance by robots. They stay on Mars for an extended period – nominally 96 months, returning not on the first, but on the fourth opportunity. They explore an extended area using pressurized rovers, perhaps driving to additional robotically-

constructed underground habitats. Such a program-level architecture affords a continuous human presence on Mars, provides better shielding from radiation, reduces the number of crew transits from and to Earth, greatly reduces the maximum mass requirement for EDL (Entry, Descent, and Landing – we would land a crew capsule, not a full habitat), permits deferred development of the return vehicle (which could otherwise be a schedule-limiting element), and allows an initial unmanned return vehicle test supported by "ground crew" to return samples to Earth. Adoption of a "base-first" exploration program will require us to acknowledge and engage the real challenges to the human exploration and colonization of Mars – maintaining the safety, health, productivity, and happiness of a very small population of humans on the surface of Mars for an extended period of time. Apollo/Saturn proved that powerful rocket systems can be developed in less than a decade – but the Mars surface stay presents many specific technical and non-technical challenges that have nothing to do with "rocket science." Now is the time to start thinking seriously about these issues.

Section X. Sex, Radiation and Reproduction on Mars: Brain, Heart, Fertility, Pregnancy, Fetal Development: Humans have sex, and pregnancy is often the outcome. If humans are to colonize Mars, they must reproduce. Sexual behavior in space and on Mars, and the effects of radiation and a Martian environment on the human genome, testes, ovaries, conception, and fetal development are discussed in the 2 papers in this section. Analogous to the early explorers on Earth, the pioneers making the first journeys to Mars and its vicinity to explore and setup a base that eventually will lead to a continuously occupied colony, will face incredible hazards, including exposure to space radiation, which is about 500 times greater in space than here on Earth. Naturally, the human body, and the human genome will be impacted, and abnormalities and even an early death may be the consequence. If humans are to colonize the cosmos, then successful pregnancies must result in a viable fetus and healthy infant. Yet, as the environment of Mars and the other planets are so different from Earth, we must also be prepared for the possibility that babies will not be viable, or may be born with mild to gross abnormalities. On the other hand, they may become adapted to their new environment, physiologically, genetically, and psychologically, and may be so different from human infants that they may appear abnormal, when in fact they may represent a new species of humanity, perfectly adapted to colonizing the cosmos.

Section XI. Robots on Mars: The exploration of Mars will be accompanied by the exploration of Mars by robotic probes are discussed by the 2 papers in this section. Robots and other unmanned systems will play many critical roles in support of a human presence on Mars, including surveying candidate landing sites, locating ice and mineral resources, installing power and other infrastructure, performing construction tasks, and transporting equipment and supplies. Many of these systems will require much more strength and power than exploration rovers. The presence of humans on Mars will permit proactive maintenance and repair, and allow tele-operation and operator intervention, supporting multiple dynamic levels of autonomy, so the critical challenges to the use of unmanned systems will occur before humans arrive on Mars. Nevertheless, installed communications and navigation infrastructure should be able to support structured and/or repetitive operations (such as excavation, drilling, or construction) within a "familiar"

operating area with an acceptable level of remote operator intervention. This paper discusses some of the factors involved in developing and deploying unmanned systems to make humans' time on Mars safer and more productive, efficient, and enjoyable.

Section XII. Terraforming Mars: Is it possible to make Mars more Earth-like for the future human colonization of the Red Planet? The answer may be terraforming, as described in the 2 papers in this section. Increasing the temperature and atmospheric pressures on Mars are considered to be the two main requirements for making Mars habitable for human life. Among the several methods to achieve such a change, the release of artificial greenhouse gases to increase temperatures by about 20 degrees at the Mars poles in order to trigger the evaporation of CO₂ ice is considered as being one of the more feasible approaches.

Section XIII. Marketing Mars: The Mars Prize: How do we finance the greatest adventure in the history of humanity? The human exploration of Mars is an expensive endeavor. New and novel approaches to financing the human exploration and colonization of Mars are discussed in the 2 papers in this section. The conquest of Mars and the establishment of a colony on the surface of the Red Planet could cost up to \$150 billion dollars over 10 years. These funds can be easily raised through a massive advertising campaign, and if the U.S. Congress and the governments of other participating nations, grant to an independent corporation ("The Human Mission to Mars Corporation," a hypothetical entity), sole legal authority to initiate, administer, and supervise the marketing, merchandizing, sponsorship, broadcasting, and licensing initiatives detailed in this article. It is estimated that \$10 billion a year can be raised by clever marketing and advertising thereby generating public awareness and enthusiasm, and through the sale of Mars' merchandise ranging from toys to clothing. With clever marketing and advertising and the subsequent increase in public interest, between \$30 billion to \$90 billion can be raised through corporate sponsorships, and an additional \$1 billion a year through individual sponsorships. The sale of "naming rights" to Mars landing craft, the Mars Colony, etc., would yield an estimated \$30 billion. Television broadcasting rights would bring in an estimated \$30 billion. This comes to a total of up to \$160 billion, and does not include the sale of Mars' real estate and mineral rights and other commercial ventures.

It seems most appropriate to conclude this introduction with the words of Dr. Straume, Blattnig and Zeitlin, from their introduction to their paper in Section X:

Since the dawn of human evolution on the African continent, our history on Earth has been one of migration, colonization and increasing population. As people outgrew their place of birth, they set forth to find opportunities in new lands. On a million- year time scale, we have finally colonized the entire Earth. In the not too distant past it was expected that the family remaining behind may never see their loved ones again when they sailed off to America. In less than 100 years, technology has made possible low cost rapid transportation between continents so that what used to require months now requires only hours. So too, will our journey into the cosmos be made increasingly accessible through technological advances. It should be expected as a matter of natural

progression that as we outgrew our birthplace we will eventually outgrow our birth planet. Colonization of space is inevitable--just a matter of time. The first colony is likely to be on Mars because of its proximity to Earth and its Earth-like environment.

To this statement, we must add: The colonization of Mars will be the first step to human colonization of the cosmos.

Onward to Mars! Let the journey begin!